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Research Article

Custom Filter-based Enhancement of MRI Images for Impulse Noise

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Abstract. This paper introduces a novel approach for enhancing MRI images corrupted by impulse noise. Impulse noise often degrades image quality, especially in medical imaging applications where accurate representation is critical. The proposed method employs a custom filter to remove impulse noise while maintaining essential image features. The custom filter is designed by altering the average value of its surrounding pixels depending on whether the pixel is entirely black or completely white. The filter's design is determined by the specifications of MRI images and noise patterns typically encountered in such data. The proposed custom filter exhibits the effective operation of the denoising technique and fully utilizes the benefits of the improved median filter in eliminating impulse noise. The results demonstrate an improvement in image quality based on various quality metrics. There is a 6% improvement in Peak Signal Noise Ratio, 0.5% in Mean Square Error, 1% in Structural Similarity Index Measure, 0.7% in Image Quality and 0.3% in Average Gradient compared to a conventional median filter. Experimental results demonstrate significant improvements in image quality and preservation of diagnostic information compared to existing methods. The proposed approach offers a promising solution for enhancing MRI images affected by impulse noise, thereby aiding in more accurate diagnosis and treatment planning in medical imaging.

Keywords. Magnetic Resonance Imaging (MRI), Image enhancement, Impulse noise, Custom filter, Medical imaging, PSNR, SSIM

Mathematics Subject Classification (2020). 65R32, 92C55, 94A08

1. Introduction

Numerous industries use digital image processing, including healthcare, manufacturing, astronomy, surveillance, and entertainment. It is essential to many industries, including manufacturing processes, such as satellite imaging, facial recognition systems, medical imaging, and quality control (Pandey and Singh [11]). It entails altering the appearance of images or extracting valuable information from them. Digital image processing is the application of computers to enhance, comprehend, and manipulate images in various ways. The fundamental step of image processing applications is image acquisition and transmission, which frequently worsens an image because of factors like dust, temperature, noise, and broken components in electronic networks. Such variables alter specific or every pixel in the image, resulting in noisy images. Several techniques are used to eliminate noise, depending on the signal or information's type and features. Filtering techniques are frequently helpful for the elimination of noise from signals. With filters, images can be altered to create various effects, like highlighting specific features, creating visuals, or enhancing image features.

A prominent medical imaging method for non-invasively visualizing internal anatomical features is *Magnetic Resonance Imaging* (MRI). The diagnostic field has been transformed by its capacity to provide precise and high-definition images, which facilitate identifying, describing, and tracking various medical ailments. Nevertheless, despite their usefulness, MRI scans can suffer from multiple noise problems, including impulse noise, which can seriously impair picture quality and compromise diagnostic precision (Aslam *et al.* [1]). Impulse noise, sometimes called burst noise, is a term used to describe a particular kind of interference or disturbance in signals or data transmission characterized by abrupt, high-amplitude spikes or pulses. The frequency, duration, and amplitude of the spikes determine the effect of impulse noise (Chen *et al.* [2]). There are various filtering techniques to reduce noise, depending on the type of noise, which improves image quality. Depending on the kind of noise and the signal or image's properties, various filters are used to reduce noise from them. When processing images and signals, a Gaussian filter is a type of image filter that is frequently used to reduce noise. However, this technique effectively blurs the image by averaging the pixel values of the surrounding pixels (Lien *et al.* [9]). The median filter is a non-linear filter that changes the value of each pixel with the average value of the neighbouring pixel. It effectively eliminates pepper and salt noise without blurring edges (Geoffrine and Kumarasabapathy [5]).

The structure of the paper includes: techniques and paradigms used today for individual and mixed noise, as stated in Section 2. In Section 3, the suggested proposed methodology for filtering individual noise is discussed. Section 4 is devoted to the relative analysis of performance parameters through several tests on distinct images in the dataset for noise reduction. The conclusion based on simulation results is presented in the last section.

2. Related Work

Many image enhancement methods have been developed to decrease the impact of impulsive noise in MRI images and address this issue. These techniques usually entail using filters or algorithms created to reduce noise while keeping the essential details of the images.

Conventional filters, like median or mean filters, might only sometimes produce acceptable results, especially in MRI pictures where maintaining suitable contrasts and tiny details is essential for accurate clinical diagnosis (Deepa and Sumithra [4]). The appearance of impulse noise, sometimes mentioned as salt-and-pepper noise, is characterized by sporadic, bright, and dark pixels that resemble random spikes dispersed throughout the image. Electronic interference, broken equipment, or transmission mistakes throughout acquiring an image are just a few possible causes of this noise. Its presence in MRI scans can skew the doctor's interpretation of the pictures, masking crucial anatomical information and distorting tissue boundaries.

Traditional filtering algorithms are classified into two main types: frequency domain and spatial domain. The median, mean, Gaussian, and bilateral filtering are examples of spatial filtering methods. This method processes existing pixels directly. Among all the algorithms available for eliminating pepper and salt noise from images, traditional median filtering is a widely applied and suitable method. This technique replaces every pixel's Gray value in the original image with the average quantity of pixels adjacent to a small window, effectively suppressing impulse noise. It is feasible to maintain the image edge and other details better. Using the neighbourhood median in an algorithm to alter each pixel in the noise image has the disadvantage of losing its ability to denoise and filter well in high-density noise pollution situations. The texture details become hazy, and the edges are prone to shifting.

Consequently, several enhanced median filtering algorithms were included in this work (see, Jeevan and Krishnakumar [8], Jain and Tyagi [7], Mehdi *et al.* [10], and Roy *et al.* [15]). Shrestha [18] proposed an enhanced multilevel algorithm for median filtering. The algorithm is capable of preserving image information more effectively and significantly. However, because the soft threshold function has a fixed deviation and the hard threshold function is discontinuous, the restored image signal will oscillate, and the denoised image will have overly smooth or blurry borders. To produce a more accurate denoising effect, numerous scholars have proposed numerous improved wavelet threshold functions (see, Das *et al.* [3], and Zhang *et al.* [19]).

A novel wavelet threshold algorithm was presented by Qian [14], which improves both the threshold and the wavelet threshold function while resolving the fixed deviation and discontinuity issues with the conventional one. Initially, the algorithm computes the weighted average quantity of the neighbourhood of all pixels in the image and the neighbourhood of the current pixel. The denoised value of the current pixel is the addition of the product of the weight and all pixels. Due to their over- completeness and sparsity, sparse regularization-based denoising algorithms have drawn the interest of numerous academicians in recent years. The study's findings demonstrate that there are various methods for denoising images. Still, several issues could arise in further investigation to raise the quality and correctness of image filtering methods (Hussein *et al.* [6]). This research investigated an analysis based on comparing the design and output of a cutting-edge algorithm to eliminate impulsive noise from grayscale images. Despite the technique's growing popularity, edge preservation, blurring, and high noise density remain the primary issues (Sen *et al.* [16]). This work covers a comparative study of the median filter and its modifications for reducing spike noise from deteriorated images. This work's conclusion can be extended to mitigate the blurring effects in the final image with existing techniques (Shah *et al.* [17]). Patil and Bendre [12] describes problems related to filtering while using different techniques using hardware and software tools. This PSNR improvement from both filters (which act on mixed noise types) is less than the median filter (which acts on single noise type) and more significant than that from the Gaussian filter (which contains single noise) (Patil and Bendre [13]).

In this regard, applying custom filters designed exclusively for MRI images will offer a viable method of improving image quality and reducing the effect of impulsive noise. Custom filters can be made to take advantage of the distinct qualities.

MRI data and the particular noise patterns found in medical imaging applications instead of generic filters. Custom filters can reduce noise artefacts while keeping diagnostic integrity and crucial image features.

3. Methodology

The main objectives of this study are developing and assessing a novel custom filter for improving MRI images impacted by impulse noise. The suggested filter minimizes distortion, preserves image features, and detects and adaptively suppresses noise artifacts. The effectiveness of the custom filter is evaluated in terms of noise reduction, improving image quality, and maintaining diagnostic information through extensive testing and comparison analysis.

A detailed structure of the proposed methodology is as per Figure 1. The custom filter is designed for impulse noise removal to enhance image quality. The experiment is conducted on a grayscale image of size 3×3. MATLAB of version R2013 is used as a tool for experimentation purposes. Input noisy image is applied to different filter techniques, including median and custom. Then, the output image parameters for specific metrics are calculated compared to the original image.

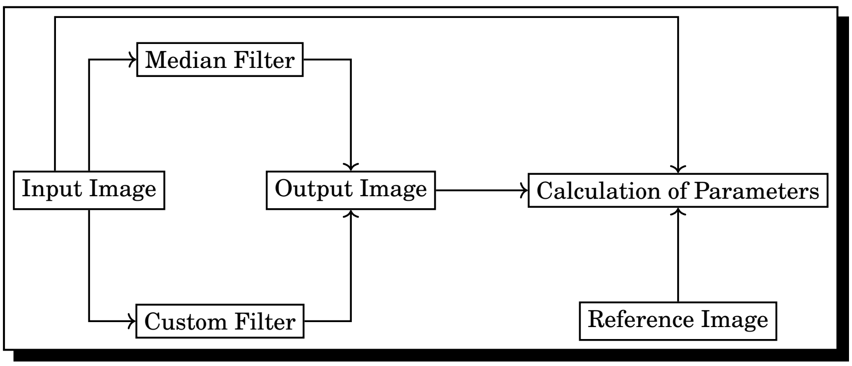


Figure 1. Framework of proposed method

3.1 Dataset: Chest CT-Scan Dataset

The proposed methodology takes images from "Kaggle", the standard dataset. From this dataset, a total of 50 images of different chest cancers are taken. Then, the two other databases are considered. The reference clean photos are contained in the first database folder and are artifacts-free. The second folder only includes noisy images with a noise similar to impulse labelled as Database_noisy_SP. These noisy images are input images to the median and custom filters. The filtered images are compared with the original images.

3.2 Image Filtering

An image processing technique called image filtering is used to improve, alter, or extract information from digital images. Creating a new image involves applying a filter, also called a kernel or mask, to each pixel in the original image to form a new image. The filter changes the intensity values of the individual pixels based on their neighbouring pixel. Images can be blurred, sharpened, or highlighted with the help of filters. Image filtering has uses in everything initiated, including noise reduction, image enhancement feature extraction, and pattern recognition. If impulse noise is present in the input image, apply the median and custom filter.

3.2.1 Median Filtering

A median filter is one of the non-linear digital filtering techniques used to eliminate noise from an image or signal. It changes the intensity of every pixel value with the average value of the pixel values in its neighbourhood. The value in the middle of the sorted list is the median if the count of pixels is odd. The median is the average of the two middle values if the count of pixels is even. Given an image I, let $I(a,b)$ represent the pixel's intensity at coordinates (a,b).

The way the median filter operates is as follows:

(i) For each pixel $I(a,b)$, define its neighbourhood $N(a,b)$.

(ii) Sort the pixel values in the neighbourhood $N(a,b)$.

(iii) Change the pixel value $I(a,b)$ with a median value of the sorted neighbouring values.

The degree of filtering is determined by the neighbourhood's size, which is commonly shown by a $k \times k$ window. k is frequently chosen to be 3, 5, 7, etc. In our case, it is 3×3. Mathematically, the way to express the output of the median filter $O(a,b)$ at coordinates (a,b) is given by equation (3.1).

$$\text{median } O(a,b) = \text{median}(N(a,b)) \tag{3.1}$$

More prominent neighbourhoods are typically used for more robust noise reduction, but this may cause the image's details and edges to become blurry. Finally, the code displays the filtered image and sets the title of the image window to 'Median Filtered Image'.

3.2.2 Custom Filtering

The code determines the neighbourhood of each pixel. The pixel's intensity value changes by the average quantity of its surrounding pixels if the pixel is entirely black (zero) or completely white (255). This contributes to noise reduction and enhanced image quality. This improved median filter works as follows:

if(img$(a,b) = 0$ or img$(a,b) = 255$), then,

$$\text{filt}(a,b) = \begin{cases} \text{img}\left(\frac{n+1}{2}\right), & \text{if } n \text{ is odd,} \\ \frac{\text{img}(\frac{n}{2}) + \text{img}(\frac{n+1}{2})}{2}, & \text{if } n \text{ is even} \end{cases}$$

otherwise

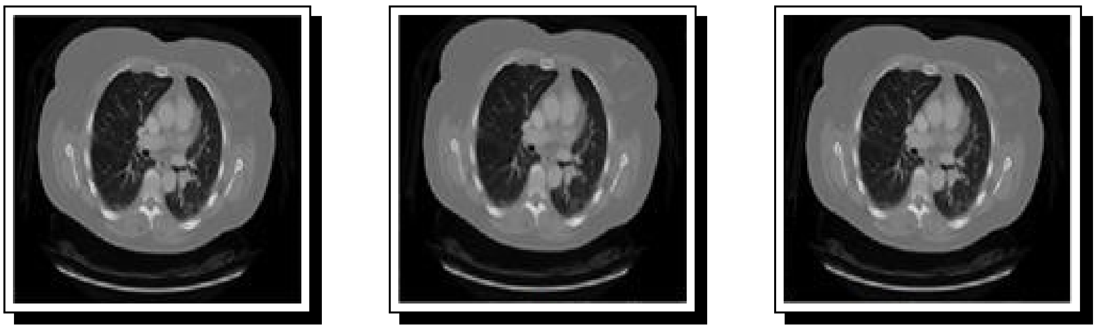
filt(a,b) = img(a,b).

The input image can be represented as a row × col 3D matrix, where each element denotes a pixel's intensity value. By choosing the pixels close to each pixel (a,b) in the image, a three-by-three window is created that is 3×3. Median filtering is applied if the intensity value of the center pixel (a,b) lies among black and white. The vector pixels contain the extracted and stored intensity values of the pixels inside the 3×3 image size. To determine the median value, these intensity values are organized in arising order. The median intensity quantity is then used to alter the center pixel (a,b). Finally, the code displays the filtered image and sets the title of the image window to 'Custom Filtered Image'.

4. Simulation Results

After experimentation with 50 images for the proposed methodology, results regarding output images were achieved. These output images contain the original, median, and custom-filtered images shown in Figure 2, 3, and 4. From the observation of quality metrics, image 15 has the highest PSNR value than other images.

4.1 Result images of Median and Custom Filter



(a) Original **(b)** Median filtered **(c)** Custom filtered

Figure 2. Output results of image2

(a) Original **(b)** Median filtered **(c)** Custom filtered

Figure 3. Output results of image15

(a) Original **(b)** Median filtered **(c)** Custom filtered

Figure 4. Output results of image6

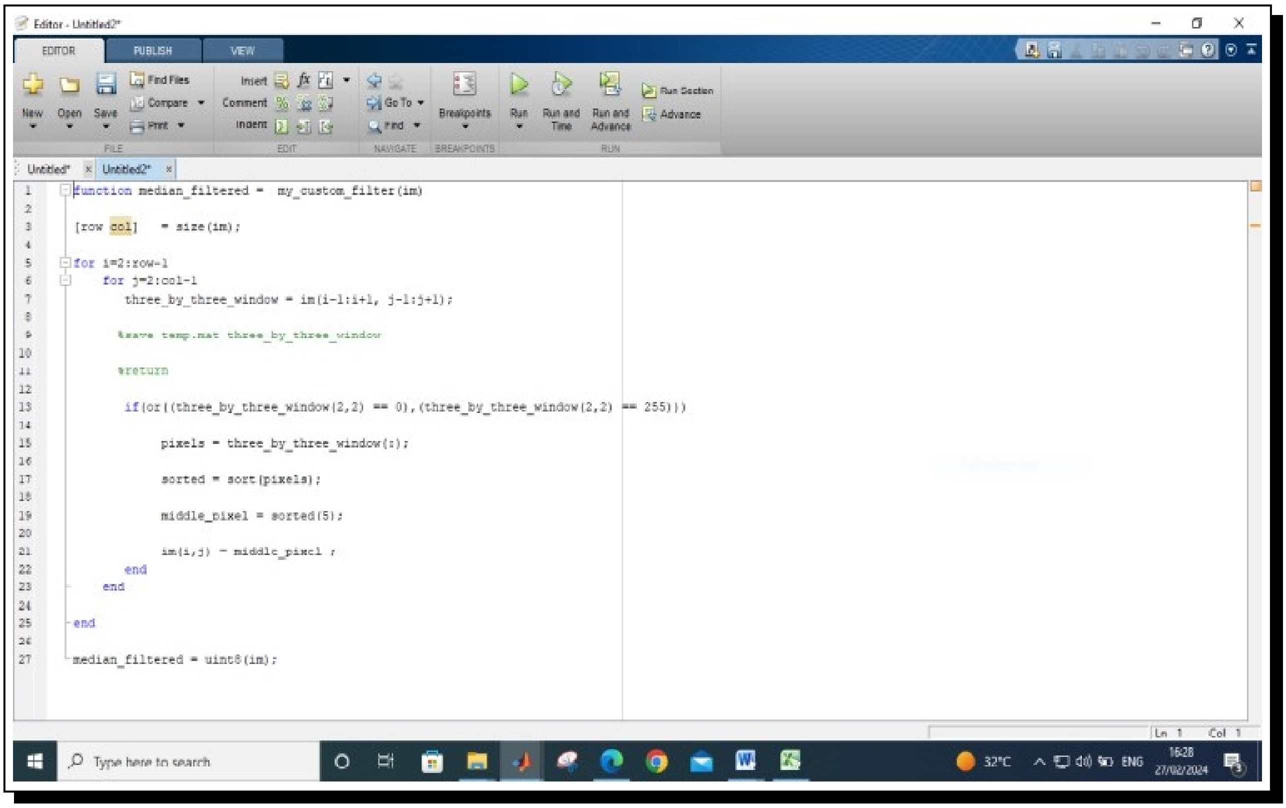
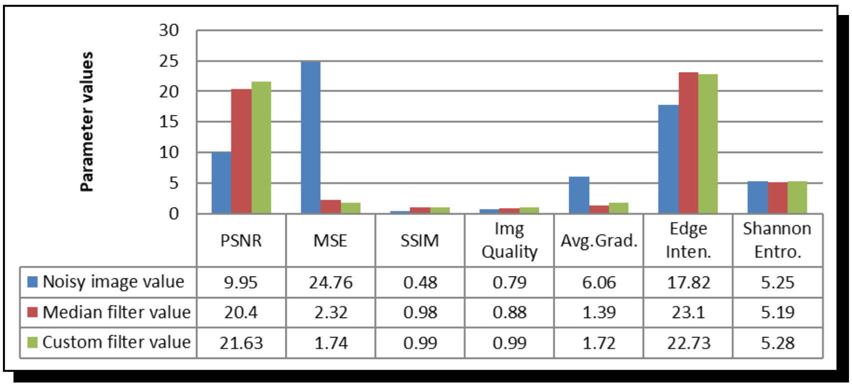


Figure 5. Code snippet of custom filtering

The above code in the snippet (refer to Figure 5) performed custom filtering for the image containing impulse noise. It applied an improved median filtering technique described in Section 3.2.2. Quality metrics were calculated before applying noisy images to filters. Then, the input image was applied to both the median and custom filter; afterwards, quality metrics were observed before and after filtering. From this result table of 50 images, the best result for image15, shown in Figure 6, and various parameters in quality metrics. Out of 50 images, the line chart of 30 images for observed PSNR values is shown in Figure 7. From the line chart, it is clear that PSNR value improved in the custom filter as compared to the median filter, which is distinguished by different colors in the graph and noise removed from the noisy image to get a clear image which is similar to the original image in terms of other parameters such as SSIM value 0.99 is near to approximately 1.



	PSNR	MSE	SSIM	Img Quality	Avg.Grad.	Edge Inten.	Shannon Entro.
Noisy image value	9.95	24.76	0.48	0.79	6.06	17.82	5.25
Median filter value	20.4	2.32	0.98	0.88	1.39	23.1	5.19
Custom filter value	21.63	1.74	0.99	0.99	1.72	22.73	5.28

Figure 6. Quality metrics of image15

4.2 Performance Parameters Results

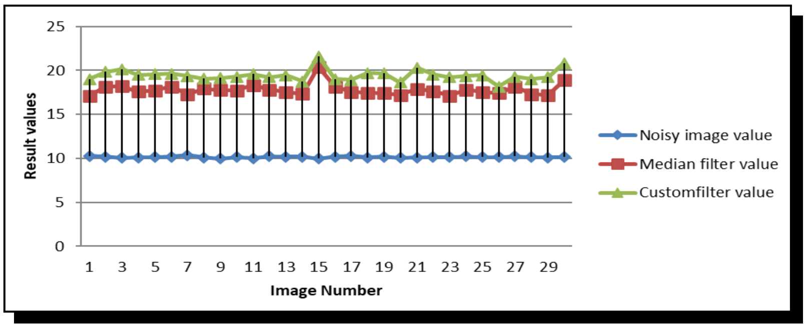
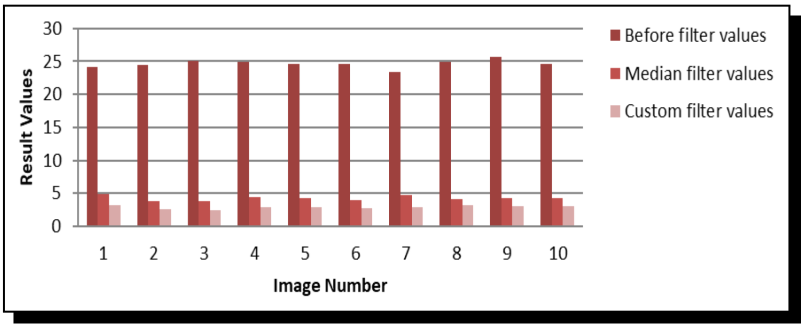
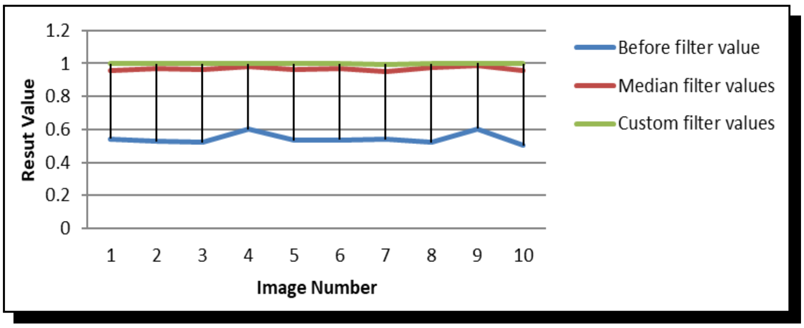


Figure 7. Line chart of 30 images for PSNR values

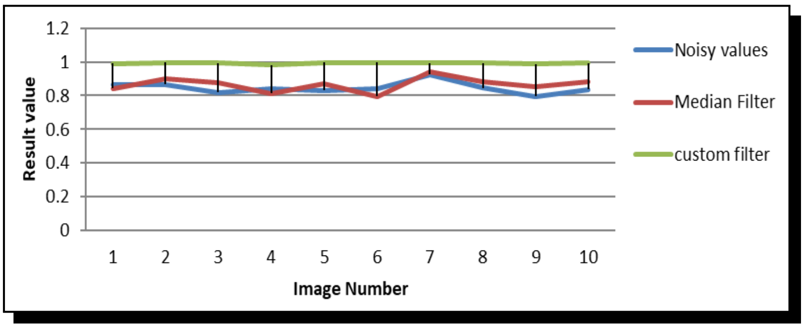


(a) MSE

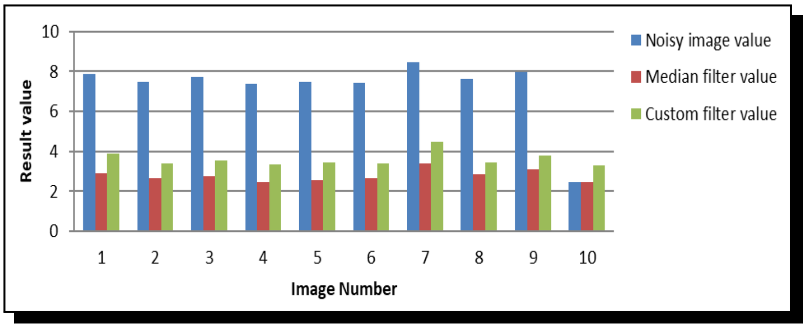


(b) SSIM

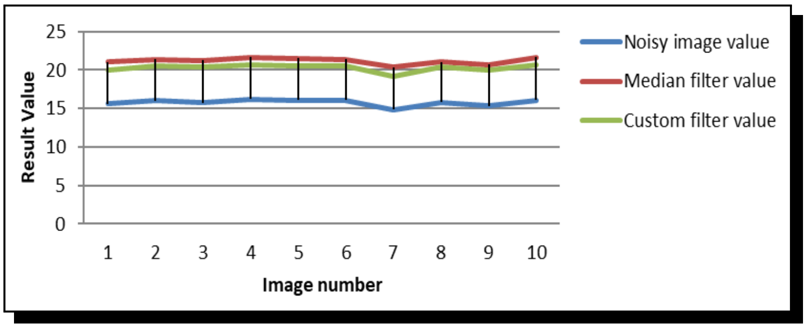
(Table *Contd.*)



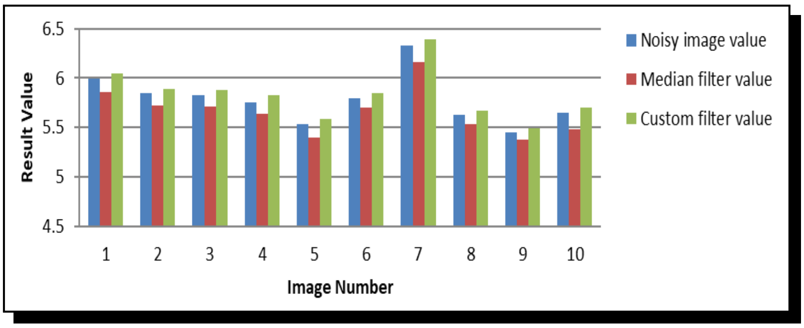
(c) Image quality



(d) Average gradient



(e) Edge intensity



(f) Shannon entropy

Figure 8. Line chart and graph of 10 images with different quality metrics

From the experiment analysis of 50 images, the result values of 10 images were observed by different graphs and chart plots for all performance parameters (refer to Figure 8). From the observation, the MSE value is less for all images. At the same time, in custom filtering, it is better. In the case of SSIM for custom filter, all image values are near 1, which is close to the standard value. For Image quality parameters such as Image quality, Average gradient, and Shannon Entropy, all result values are more significant than median result values, which is good. Only edge intensity is reduced compared to median filter result values. Compared with the median filter, all quality metrics values are enhanced in the case of a custom filter. So, the proposed custom filter approach is better than a median filter. From Tables 1 and 2, the value of PSNR is improved in our methodology as the dataset and density level are different. Similarly, SSIM is also enhanced, which means the image after filtering is as close as the original image without disturbing image quality.

Table 1. Comparison of PSNR values with other algorithms

Dataset	Density	KSVD	WNNM	TWSC	OCTOBOS	Custom
Lena	0.06	21.57	20.24	20.99	18.61	
Barbara	0.06	20.64	19.78	20.38	17.84	
Cameraman	0.06	20.27	19.14	19.72	17.76	
Chest	0.05					21.63

Table 2. Comparison of MSE values with other algorithms

Dataset	Density	KSVD	WNNM	TWSC	OCTOBOS	Custom
Lena	0.06	0.3677	0.3846	0.4545	0.2547	
Barbara	0.06	0.435	0.4132	0.5191	0.3134	
Cameraman	0.06	0.3766	0.3894	0.4376	0.2864	
Chest	0.05					0.99

The proposed filter adaptively identifies and suppresses noise artefacts while preserving image details and minimizing distortion. Through comprehensive experimentation and comparative analysis, the *efficiency* of the custom filter is assessed in terms of noise reduction, image quality enhancement, and preservation of diagnostic information.

5. Conclusion

This paper added some impulse noise to the chest MRI images at a 0.05 density. This work applied the noise and then put our suggested algorithm into practice. The proposed approach is suitable for reducing the image's noise by analyzing the difference from the figures. However, there is also no reduction in visual quality. Therefore, this work may significantly shorten the time needed for the disease's pre-diagnosis by employing this updated method for medical imaging. In contrast to all previous filter forms, the modified form of the median filter produces better results by maintaining the edges. We can see from the output images that the custom filter produces the intended effects.

Except for edge intensity, which is lower when compared to the median, custom filtering will perform better than median filtering in terms of noise removal. From the comparison of both filters for all 50 images, the better result is listed here as follows in which most of the *parameters* like PSNR (21.63), MSE (1.74), SSIM (0.99), Image Quality (0.99), Avg. Gradient (1.72), Edge Intensity (22.73), Shannon Entropy (5.28).

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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